Continued Development of the Look-up-table (LUT) Methodology for Interpretation of Remotely Sensed Ocean

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Award Number: N0001406C0177
http://www.onr.navy.mil/sci_tech/32/322/ocean_optics_biology.asp

LONG-TERM GOAL

The overall goal of this work is to refine and validate a spectrum-matching and look-up-table (LUT) technique for rapidly inverting remotely sensed hyperspectral reflectances to extract environmental information such as water-column optical properties, bathymetry, and bottom classification.

OBJECTIVES

My colleagues at the Florida Environmental Research Institute and I are developing and evaluating techniques for the extraction of environmental information including water-column inherent optical properties (IOPs) and shallow-water bathymetry and bottom classification from remotely-sensed hyperspectral ocean-color spectra. We address the need for rapid, automated interpretation of hyperspectral imagery. The research issues center on development and evaluation of spectrum-matching algorithms, including the generation of confidence metrics for the retrieved information.

The present work, which is just starting, continues investigations that were previously funded under a different contract (see the associated report for previous results). The on-going work will continue the evaluation, refinement, and optimization of the LUT technique including, in particular, applications to turbid coastal waters, inhomogeneous water columns, and optically deep waters.

APPROACH

The LUT methodology is based on a spectrum-matching and look-up-table approach in which the measured remote-sensing reflectance spectrum is compared with a large database of spectra corresponding to known water, bottom, and external environmental conditions. The water column and bottom conditions of the water body where the spectrum was measured are then taken to be the same as the conditions corresponding to the database spectrum that most closely matches the measured spectrum.

Previous applications of the LUT methodology have been to optically shallow waters in the Bahamas and Florida Keys. That work showed that LUT is robust and can successfully retrieve water column IOPs, bottom depth, and bottom classification at each pixel from hyperspectral remote-sensing reflectance R_{rs} spectra (Mobley et al., 2005). The next step of this work will address several basic science issues that are central to the realizing the full potential of the LUT methodology. In particular,

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE **30 SEP 2006**		2. REPORT TYPE			3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Continued Development of the Look-up-table (LUT) Methodology for Interpretation of Remotely Sensed Ocean**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Sequoia Scientific, Inc,2700 Richards Road, Suite 107,Bellevue,WA,98005**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

the following questions are being addressed:

- How well does LUT perform when we go beyond the clear, shallow waters, which have been considered in LUT evaluations to date, and perform retrievals in more turbid coastal waters?

We now have in hand extensive imagery of coastal California waters (e.g., the CI-CORE data set, which includes over 5,000 square kilometers of three-meter hyperspectral imagery for Humboldt Bay, San Francisco Bay, Monterey Bay, the Big Sur coast, San Luis Bay, Santa Barbara, Newport, and San Diego Harbor; see www.flenvironmental.org/projects/ci-core/). This imagery is being used for evaluation of LUT in turbid coastal waters.

- How are LUT retrievals of bathymetry, bottom classification, and IOPs affected if the LUT database of R_{rs} spectra was created assuming that the water is homogeneous with depth, but the imaged water body has vertically stratified IOPs?

Idealized simulations of retrievals for clear shallow waters have shown that water-column inhomogeneity does not cause great errors in retrievals of bathymetry and bottom classification (Mobley, 2004). However, we are uncertain if inhomogeneous waters will lead to substantial errors in retrievals in optically turbid or deep waters.

We will perform retrievals of simulated Rrs spectra using databases with homogeneous vs. inhomogeneous R_{rs} spectra to quantify the effects of water column inhomogeneities on various types of retrievals. If these studies show that it is necessary to include inhomogeneous IOPs in the LUT R_{rs} database, then several questions arise. Can the effect of stratified water IOPs on R_{rs} be captured by just a few (maybe 2 or 3) homogeneous layers, each with absorption, scattering, and backscattering coefficients that are independent of depth within a layer? What layer depth and thickness affects are there on the LUT retrievals in inhomogeneous waters? Can an inhomogeneous water column be replaced by a homogeneous water column whose IOPs are exponentially-weighted depth averages of the inhomogeneous IOPs?

- How well does LUT perform in optically infinitely deep waters, in which case only the IOPs are being retrieved?

To date, the primary products of LUT retrievals have been bathymetry and bottom classification. In very clear, shallow waters, the water-leaving radiance is dominated by bottom reflectance, with the water-column IOPs being of secondary influence. In optically deep waters, the water-leaving radiance is determined entirely by the water-column IOPs. The LUT spectrum matching should then return the IOPs and an infinite bottom depth. We have seen this correct behavior in offshore images from LSI. However, the present LUT database does not include a wide range of IOPs such as found in open-ocean waters. To perform deep-water retrievals it is necessary first to add deep-water R_{rs} spectra to the LUT database using Case 1 and 2 IOP models (and any available measured IOPs, such as from ac-9 measurements). LUT deep-water performance must then be evaluated via retrievals on both synthetic and actual imagery. We hope to acquire deep-water imagery and sea truth during future field campaigns for evaluation of LUT deep-water performance with real imagery. Extension of the LUT methodology for deep waters would make it widely applicable as an inversion tool for ocean-color remote sensing imagery over the open ocean.

- How can “confidence maps” for LUT retrievals best be generated?

It would be of great value for users of LUT retrievals also to have a corresponding map of the confidence in the retrievals. That is to say, a depth, bottom classification, or IOP retrieval would be accompanied by some indication (perhaps just a green/yellow/red, i.e., confident/uncertain/untrustworthy, flag) of how good the retrieval is at each pixel. We will continue to evaluate various metrics for measuring retrieval accuracy and confidence. It may be necessary to tailor the confidence metrics to different situations or products, e.g., a metric that works well for bathymetry retrievals in clear shallow water may be different from the best metric for IOP retrievals in deep waters.

- How much can improvements in atmospheric correction and sensor noise reduction improve the LUT retrievals?

At the moment, it is somewhat unclear how much of the error in LUT retrievals is do to factors relating to LUT itself, such as the absence of particular bottom reflectance spectra or IOPs in the present LUT database, and how much is due to factors such as imperfect atmospheric correction of the imagery being processed. For example, the TAFKAA atmospheric correction algorithm used to date assumes that the sky is clear. However, some of our imagery includes cloud shadows. Thus the atmospheric corrections are no doubt imperfect, which introduces corresponding errors (of unknown magnitude) into the LUT retrievals. We will continue to improve the atmospheric correction algorithms and to examine such effects on the LUT retrievals.

- How can the LUT data processing be improved?

In the course of the LUT work to date, a considerable amount of computer code has been written. Some of this code involves proprietary search and spectrum-matching algorithms, which have speeded up the processing times by more than an order of magnitude, compared to our initial brute-force techniques. This code and algorithm optimization is continuing.

WORK COMPLETED

A preliminary analysis has been performed on imagery from Humboldt Bay, California to evaluate LUT performance in highly turbid harbor waters, for which the bottom is visible down to only a meter or two. Some idealized work has been performed to determine the influence of stratified water on retrievals if the database contains reflectances corresponding only to homogeneous water columns

RESULTS

First-look analysis of the Humboldt Bay imagery provides bathymetry that is qualitatively correct, as seen in Figs. 1 and 2. The Humboldt Bay waters are high in resuspended sediments and terrigenous CDOM, which gives high scattering and high absorption at blue wavelengths. Figure 2 shows that over much of the image (the green areas in the right-hand figure) the LUT-retrieved bathymetry in these waters is within ±0.2 m of the LIDAR-retrieved value in waters that are 0.8 to 1.4 m deep. These encouraging results indicate that LUT is equally applicable to all water types.

IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of Navy needs as well as basic science and ecosystem monitoring and management problems. Extraction of bathymetry and bottom classification is especially valuable for planning military operations in denied access areas. This work thus adds to the existing suite of remote sensing analysis techniques for coastal waters.

TRANSITIONS

Various databases of water IOPs, bottom reflectances, and the corresponding R_{rs} spectra, along with the specialized HydroLight code and spectrum-matching algorithms have been transitioned to Dr. Paul Bissett at the Florida Environmental Research Institute for processing his extensive collection of SAMPSON imagery now being acquired in coastal California waters.

RELATED PROJECTS

This work is being conducted in conjunction with Dr. Paul Bissett of FERI, who is separately funded for this collaboration. His ONR annual report should be consulted for the details of his contributions to the overall LUT development.

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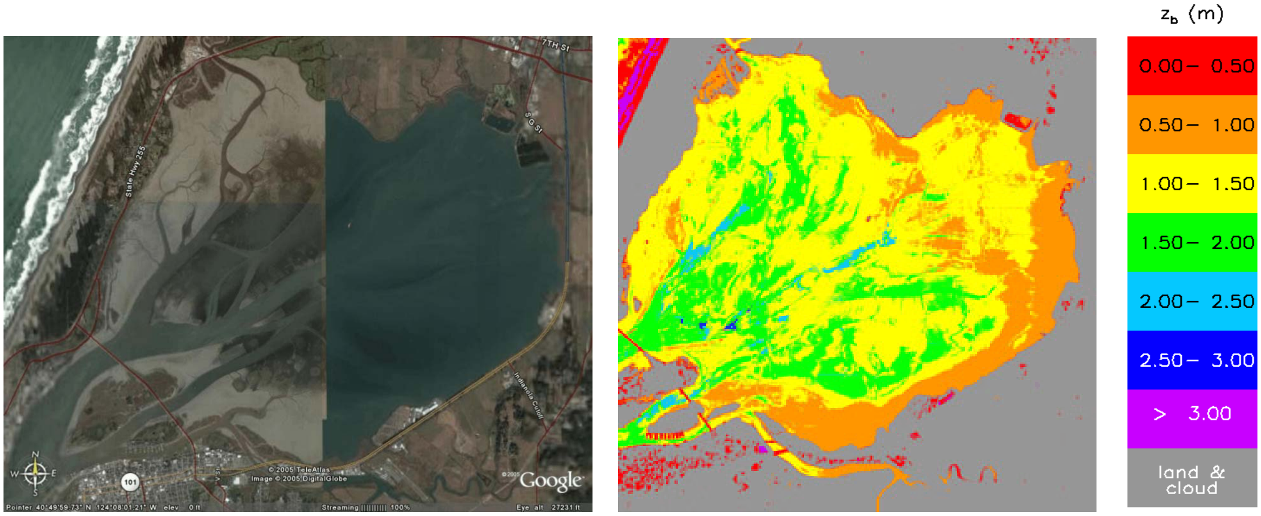

Fig. 1. Left image: Composite satellite image of the north part of Humboldt Bay, California. The left half of the image shows that the bay drains to mud flats with a few deeper channels at low tide. The right half shows the bay near high tide, when the entire bay is covered by water. The tide range here is about two meters. The right image shows the LUT depth retrieval, made from PHILLS2 images acquired near high tide.

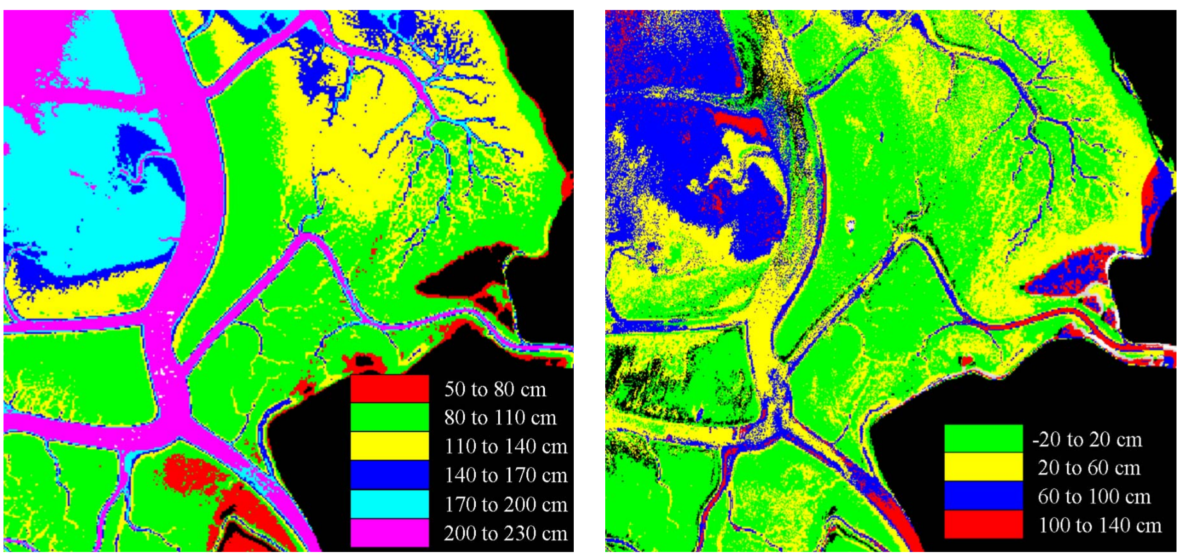

Fig. 2. Comparison of LUT and LIDAR bathymetry in the south part of Humboldt Bay, CA. The left figure shows LIDAR bathymetry estimates calculated by estimating the tidal height above the MLLW for which this data was collected. The channels in magenta are actually deeper than shown, but the topographic LIDAR system was not able to penetrate the water. The right figure shows the difference between the LIDAR estimated bathymetry and LUT estimated bathymetry. The greatest difference is in the NW corner and along channel edges. These regions correspond to high concentrations of eel grass, which may extent upwards to 2 m above the bottom.